INSTRUCTION MANUAL

FOR THE

METAL FILM GAUGE
TYPE 255-A

BOONTON RADIO CORPORATION
BOONTON, NEW JERSEY
U. S. A.

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Printed in U.S.A.

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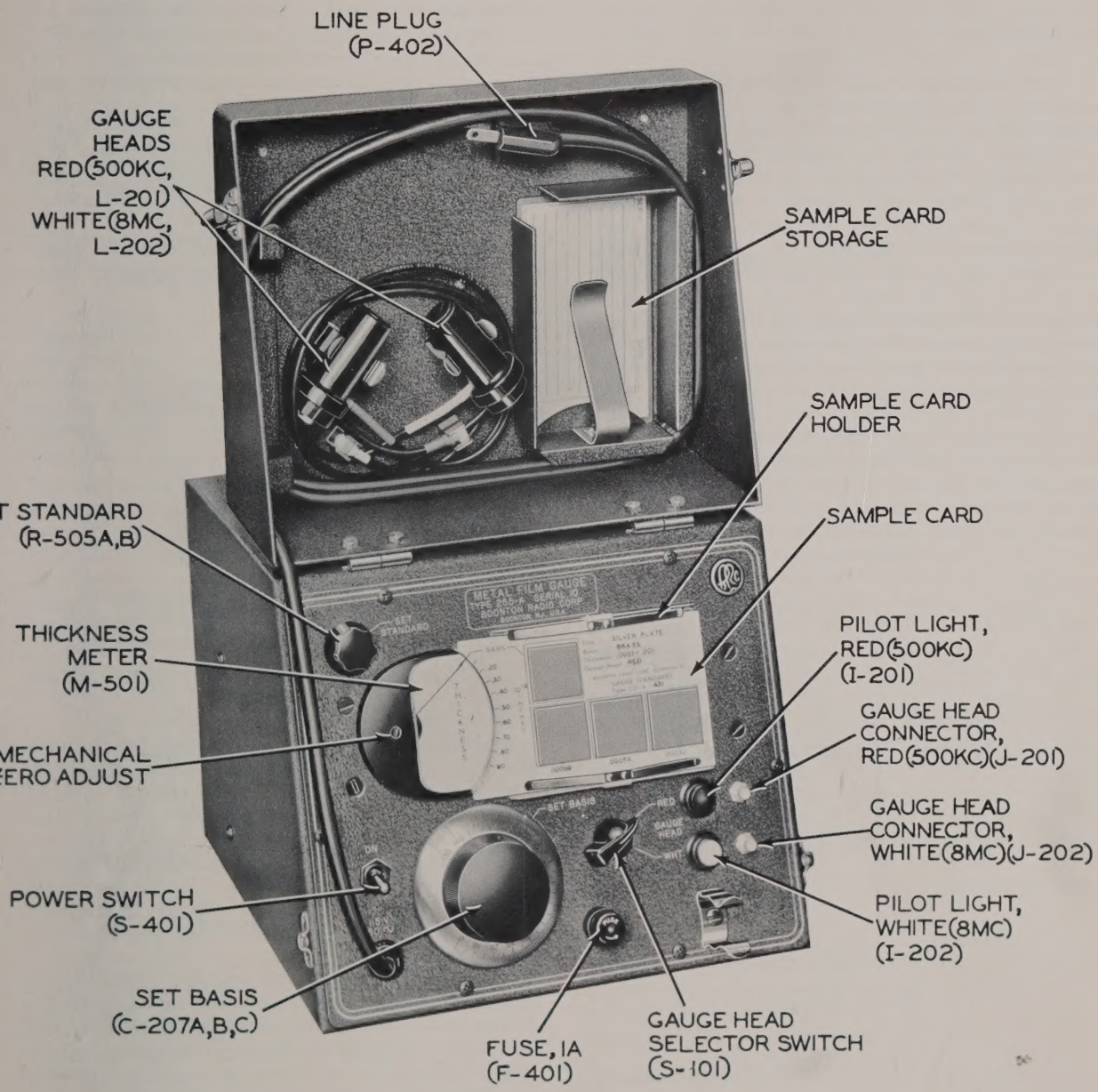


Figure 1. Front Panel Controls and Layout

SECTION I
GENERAL DESCRIPTION

INTRODUCTION

The Metal Film Gauge Type 255-A indicates the thickness of coatings directly. It is non-destructive, simple and fast in application, accurate and reliable to within a few percent, and portable. With appropriate materials and thicknesses, the 255-A can measure film thicknesses of three kinds: conductive films on conductors; conductive films on non-conductors and non-conductive films on conductors. The absolute accuracies obtainable with the instrument depend on the accuracy with which the thicknesses of the standards can be determined. The instrument by itself is capable of distinguishing between film thicknesses differing by only a few percent of the thickness corresponding to full scale when the correct gauge head is used.

Two complete gauge head assemblies go with each instrument for use with different thicknesses of films and combinations of materials. The gauge heads are connected to the instrument by 30 inches of miniature coaxial cable with matching connectors and are easily detachable. The encapsulated gauge head coil is carried on a lightly spring-loaded plunger which can move up and down in a hand-held shell. The lower end of the shell contains three symmetrically placed bosses whose purpose is to insure perpendicularity of the gauge coil axis to the specimen under investigation.

The cover of the instrument has storage facilities for the gauge heads, cord and sample cards for use when storing or transporting the instrument. It can also be used as a stand for the instrument if desired, increasing the inclination of the front panel by an additional 15 degrees and raising the instrument about three inches. A handle is provided for greater portability.

SPECIFICATIONS

Film Thickness Range: For a given combination of materials each Gauge Head covers a range of 5 to 1. Because of overlap the two heads cover a combined range of about 20 to 1.

Accuracy: Indicates the plating thickness of unknown samples over Thickness Range within ±10% assuming no tolerance in accuracy of calibrating samples.

Stability: After fifteen minute warmup period, readings will drift no more than ±5% near full scale per thirty minutes. Readings may be restandardized against calibration samples at any time.

Accessories Furnished: One Red Gauge Head (500 kc)
One White Gauge Head (8 mc)
One Instruction Book
Four Gauge Standard Cards (Blank)

Available: Gauge Standard Cards with various material combinations and thicknesses will be announced from time to time. Inquiry is invited as to price and availability of Gauge Standard Cards to meet your needs.

Tube Complement: 1-12AU7, 2-6CS6, 1-6BN6

Power Requirements: 95-125 volts — 60 cps only (internally regulated) power consumption is 35 watts. Type 255-AP available for operation from 95-125 volts 50 cps only. Power consumption is 35 watts.

Size: *Height* 8 9/64 max.
Width 10 9/64 max.
Depth 11 23/32 max.

Weight: 30 lbs. net
50 lbs. gross packed for export.
32 lbs. gross packed for domestic.
31 lbs. legal weight packed for export.

SECTION II
APPLICATIONS AND MEASURING TECHNIQUES

MEASUREMENT OF FLAT SAMPLES

The use of the Metal Film Gauge Type 255-A in making film thickness measurements on flat samples of non-magnetic metal combinations is simple and straightforward when a calibrated sample card is available containing the two metals in question. It consists of adjusting the instrument for the basis material with the Gauge Head set on the basis material by means of the *Set Basis* control and of calibrating the meter scale to a known thickness on the standard sample card by means of the *Set Standard* control. The instrument is then ready to measure film thickness on unknown samples of the two metals within the thickness range on the meter scale. An area of at least ½" of continuous surface is generally required for measurement.

MEASUREMENT OF NON-CONDUCTIVE FILMS ON CONDUCTIVE BASIS MATERIAL

The same simple procedure is used when measuring non-conductive films on a conductive basis material or for measuring the thickness of a conductive coating on a non-conductive basis material. It is of course necessary to establish a standard sample card for reference purposes. This procedure is covered under Section IV. Examples of measurements on these materials include anodic films on aluminum, organic films on aluminum, various types of resins on a non-magnetic basis material, and silver, gold, chromium, etc., on a non-conductive basis material such as steatite.

MEASUREMENT OF CONDUCTIVE FILMS ON NON-CONDUCTIVE BASIS MATERIAL

Measurements can be made of a conductor deposited on one side of non-conductor. If both sides of the non-conductor have a conductive coating, the thickness of the non-conductor must be sufficient so that the presence of the conductor on the bottom side does not affect the readings made of the top side. This can be determined by measuring the thickness of a conductive coating applied to one side, then coating the bottom side with the conductive coating and making another measurement. This effect can be simulated by using two pieces with one side coated, measuring the first one, and then laying it on top of the second (with the latter's conductive side up) and verifying the first measurement.

MEASUREMENTS ON CURVED SURFACES

The instrument is sensitive to variations in gauge head-to-work spacing. Differently curved surfaces result in average coil-to-work spacings different from those of plane surfaces when the Gauge Head is brought in contact with the work. However, moderate amounts of curvature can be offset by using the "offset balance" method: the instrument is adjusted on a flat piece of basis material and calibrated on flat standards. The Gauge Head is then brought in contact with an uncoated piece of the curved material, and the *Set Basis* control readjusted to give a new zero (basis) indication on the matter. The same procedure can be used on flat materials if the actual basis conductivity is slightly different from that of the standards. If, however, the surface curvature is excessive or irregular, a jig or fixture is recommended for holding the sample and/or Gauge Head so that contact is made under identical conditions each time a reading is taken. Curved standards are required.

MEASURING TECHNIQUE WHERE GREATER SENSITIVITY IS REQUIRED

In some measurements (such as extremely thin films) it is desirable to achieve greater sensitivity of the instrument than is normally available. It is often possible to do this by zeroing the Gauge Head on a sample of the plated material rather than on the basis material. Deviation from this zero point will then be read on the meter scale of an appropriately calibrated sample card. However, care must be exercised when using this method. If the instrument is zeroed on a thin sample, all succeeding measurements should be made on samples which are thicker. If accidentally, a measurement is made on an even thinner sample, the instrument will indicate it as being thicker since the meter is designed to read all variations from the zero point in the same direction. If this possibility of a polarity error is kept in mind, the method is very useful.

MEASUREMENTS OF PLATING ON MAGNETIC BASIS MATERIALS

Measurements of plating on magnetic basis materials such as steel can usually be made on hot-rolled steel and stainless steel. Some types of cold-rolled steel vary too much from piece to piece in their magnetic characteristics for accurate measurements to be made. A simple test for this can be made: (1) zero the instrument on a sample of the basis material, (2) move the Gauge Head around on the basis sample (or other samples) and check to see that the zero point remains reasonably constant. If the zero point is constant, accurate measurements can be made.

MEASUREMENTS OF MULTI-LAYER PLATINGS

For multi-layer platings it is usually necessary to measure each type of plating before the succeeding coating is plated on. The instrument is zeroed on the basis material and calibration made on samples with the first plating added. Subsequent samples plated with the first metal are used to "zero" the instrument and measurements made on the second plating, etc. The technique described above for obtaining increased sensitivity may be of value in measuring multi-layer platings.

SECTION III
OPERATION

FRONT PANEL CONTROLS AND LAYOUT

(See Figure 1)

The entire instrument is portable and is housed in a closed cabinet with detachable hinged cover.

The front panel carries brief operating instructions, controls necessary for operation, power cord, power switch, fuse, connectors for the two Gauge Heads, two pilot lights, the indicating meter and a slide for holding the calibrated sample card (which carries a sample

of the unplated basis material together with plated samples of known thicknesses of a given metal and the appropriately calibrated meter scale).

The operating controls are:

Gauge Head Selector Switch —
Selects the applicable Gauge Head.

Set Basis Control —
Standardizes the instrument for the basis material being used.

Set Standard Control —
Matches the calibration scale to the known standards.

Power Switch —
On-Off toggle switch for controlling instrument power. A heater remains on with the switch off to keep components dry.

MEASUREMENT PROCEDURE

A Gauge Standard having the proper range of thickness and combination of materials is required. It may be prepared by the user as described in Section IV, or it may be obtained from Boonton Radio Corporation at a charge which depends on the materials and thicknesses involved.

After a proper Gauge Standard has been obtained plug in the power cord, turn the instrument on, allow a few minutes for it to warm up, and then follow the procedure outlined below:

1. Connect *Gauge Heads* to their chassis connectors using color coding on sleeving of Gauge Head cables, chassis connectors and associated pilot lights as guides.

2. Select *Gauge Standard* having desired materials and thickness range and insert in holder.

3. Select *Gauge Head* and *Switch* position having color named on *Gauge Standard*.

4. Place *Gauge Head* on Basis Standard and turn *Set Standard* control to maximum clockwise position. Adjust meter to Basis line using *Set Basis* control.

5. Place *Gauge Head* on Thickness Standard. Adjust meter to same thickness reading on scale as indicated under standard by using *Set Standard* control.

6. Place *Gauge Head* on work. Read thickness.

7. Periodically re-check steps (4) and (5).

Since both conductivity and permeability can show considerable variations in some materials, depending on the local composition of the material, its heat treatment and previous history (work hardening, etc.), care must be taken that the calibrated standards are representative of the material to be measured.

SECTION IV

PREPARATION OF GAUGE STANDARDS

DETERMINATION OF PROPER GAUGE HEAD

The Gauge Head to be used should be chosen according to the thickness of the coating and composition of the film-basis combination to be measured. In general, a thinner coating requires use of the *White* Gauge Head. Coatings of lower conductivity also require the *White* Gauge Head while those of higher conductivity with comparable thickness and having the same basis metal require the use of the *Red* Gauge Head.

These requirements can be visualized more easily by reference to Figure 2, a nomograph for use in conjunction with Figure 3, to help in the intelligent choice of Gauge Head. Figure 2 shows the anticipated sensitivity of measurement for various combinations of coating and basis materials. It also gives the factor "A" which signifies how many times the penetration depth in the coating metal should be larger than the maximum expected plating thickness. For each combination of coating and basis metals, drop perpendiculars from the boxes pertaining to the coating and basis metals to the appropriate base line of the nomograph, join these points by a straight line, and "A" is then found at the intersection of this straight line with the center line.

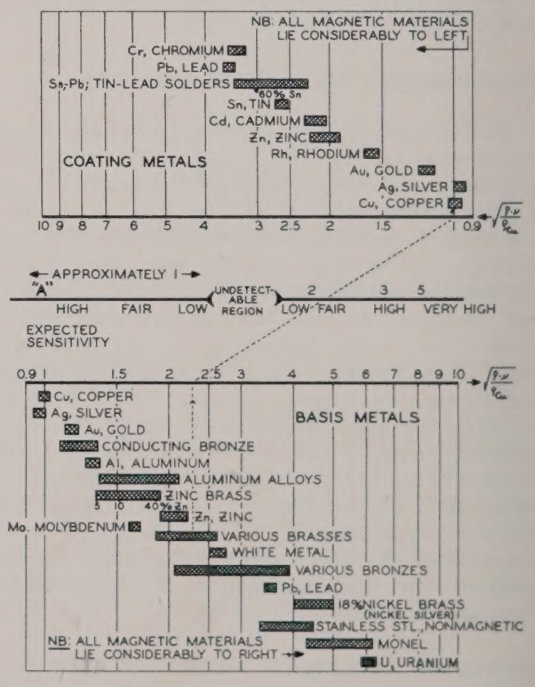


Figure 2. Combinations of Basis and Plating Materials: Expected Sensitivity and Required Ratio of Penetration Depth to Plating Thickness

Example: Assume one wishes to measure 1 mil (10^{-3} inches) of silver plating on a yellow brass of average composition. For this combination $A \cong 2$. Consequently, one should choose a Gauge Head operating at a frequency such that the penetration depth in silver will be of the order of 2 mils. From Figure 3, illustrating penetration depths, we find that this is obtained at a frequency of 1.5 mcs.

The Red Gauge Head frequency (500 kc) is somewhat lower than the required 1.5 mc and will increase the maximum measurable thickness, but some loss of sensitivity is to be expected on very thin coatings. Use of the White Gauge Head, having a higher frequency (8 mc), will prevent measuring up to the full 1 mil thickness but provides better sensitivity on very thin platings.

PREPARATION OF CALIBRATION CARDS

Since measurements with the Metal Film Gauge depend on comparing an unknown specimen with a meter scale developed from known standards, the first step in making use of the instrument for absolute thickness measurements is the preparation of suitable standards approximately 1 inch square for calibrating the instrument. For this purpose, at least two identical sets of standards of at least three thicknesses each, distributed over the thickness range to be measured, should be made up and checked as follows:

Place the proper Gauge Head, as determined above, on the bare basis material and adjust the *Set Basis* control to give a *Basis* reading on the meter with the *Set Standard* control turned fully clockwise. Corresponding samples in both sets should then produce the same meter indication.

One of the standard sets is measured by some means acceptable to the user for the actual plating thickness, while the other set is mounted on one of the Gauge Standard cards supplied with the instrument together with a piece of bare basis metal. Mount the sample of the basis material in the upper left hand square on the card. With the Gauge Head on the thickest sample available, adjust the *Set Standard* control for a near full-scale reading on the meter. A sample falling in the maximum one third of the scale, but not necessarily the thickest sample, is then cemented in the square directly below the basis sample. The other two samples may be cemented in the two remaining squares on the card, or the spaces may be used for limit samples for a particular operation.

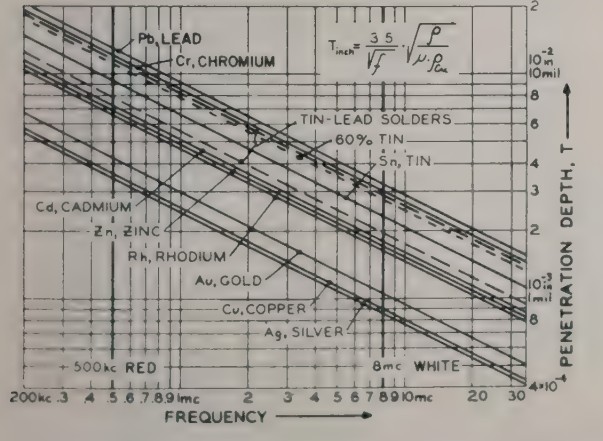


Figure 3. Penetration Depths (in inches, T) of the Most Common Plating Materials

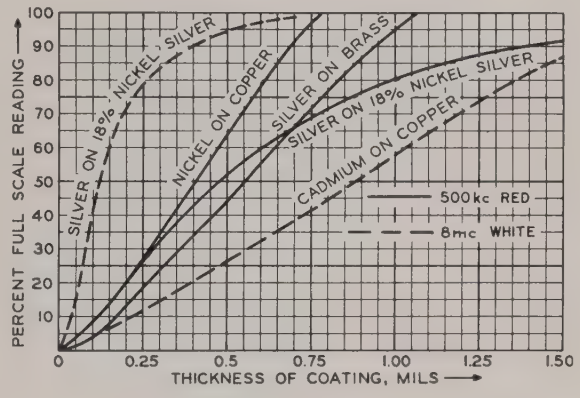
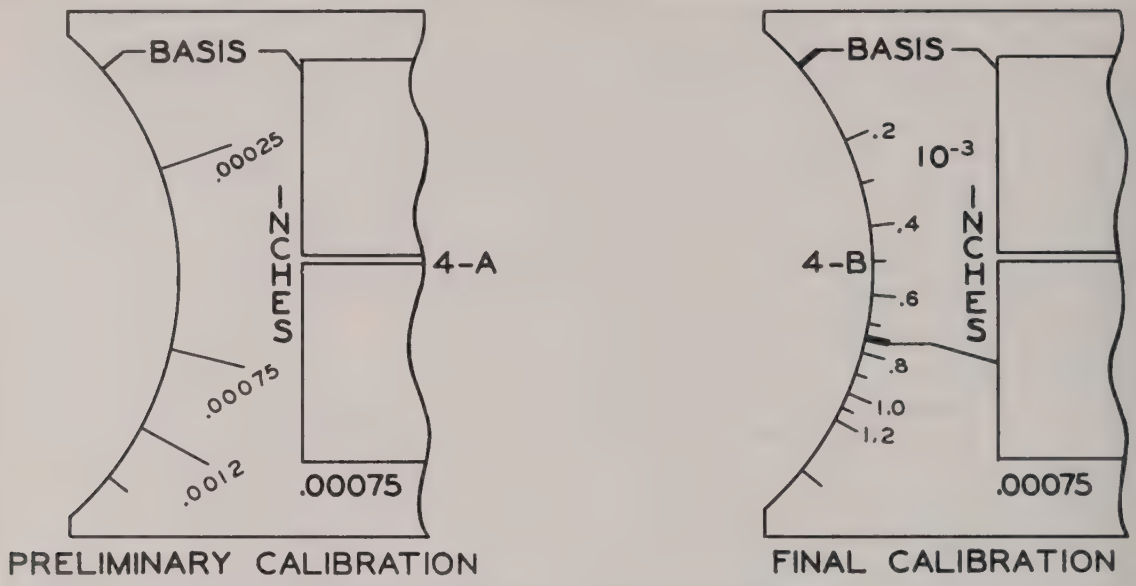

PERCENT FULL SCALE READING
THICKNESS OF COATING, MILS
SILVER ON 18% NICKEL, SILVER
NICKEL ON COPPER
SILVER ON BRASS
SILVER ON 18% NICKEL SILVER
CADMIUM ON COPPER
500kc RED
8mc WHITE
0 0.25 0.5 0.75 1.00 1.25 1.50
10 20 30 40 50 60 70 80 90 100

Figure 4. Typical Samples of Calibration Curves

All of the standard samples are measured in succession and the corresponding readings marked on the edge of the card as shown in Figure 5-a. The card is then placed on Figure 5-c and the readings on the 0-100 scale opposite the calibration marks plotted on graph paper as a function of film thickness as shown in Figure 5-d. By drawing a smooth curve through the measured points a calibration curve is obtained. This curve can be transferred to the sample card as shown in Figure 5-b. Drawing a heavy line at the thickness of the calibration standard will facilitate adjustment of the instrument. Mark the Gauge Head color, RED or WHITE, in the space provided on the card. Pencil, india ink, or ball point can be used for lettering.

The reason for using at least three calibrated thicknesses is that the shape of the calibration curve cannot be predicted with sufficient reliability. Depending on the coating-basis combination involved, curves of widely differing shape will be obtained (see Figure 4). Many curves bend sharply as they approach zero, as shown by Silver or Brass. They also level off for thick coatings as the depth of penetration is approached.



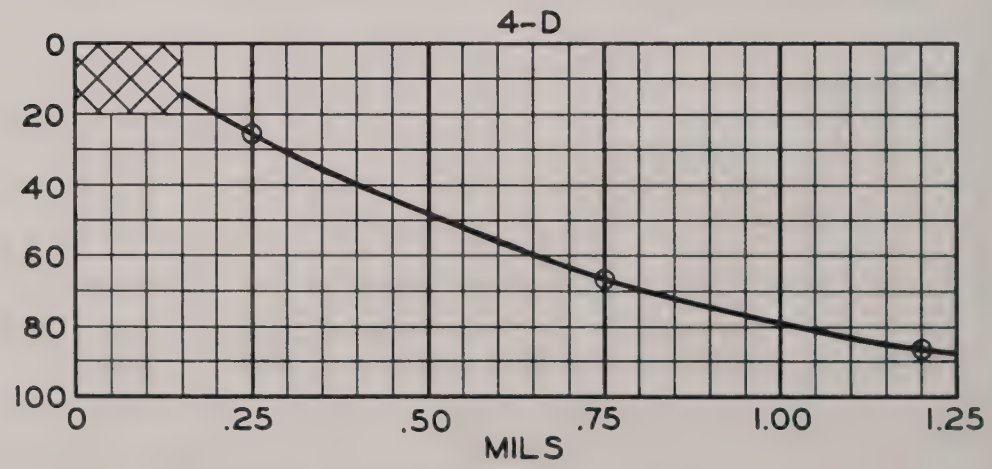


Figure 5. Generating a Calibration Curve from Samples Having Known Film Thicknesses

SECTION V
MAINTENANCE

ALIGNMENT

Note: For Step 1 use a vtvm with no more than 5 $\mu\mu$f input capacitance. For steps 4 and 5, where only relative readings are required, the input capacitance of the vtvm should be reduced by connecting a 2-5 $\mu\mu$f capacitor in series with the vtvm gauge head.

Before beginning alignment warm-up instrument for 15 minutes with the Gauge Heads attached.

1. RED range: *Set basis* on 0; vtvm on Cathode of 7.5 mc oscillator (pin 3, V-101, 12AU7).

Set oscillator amplitude to 13-15 v. with L-103 on

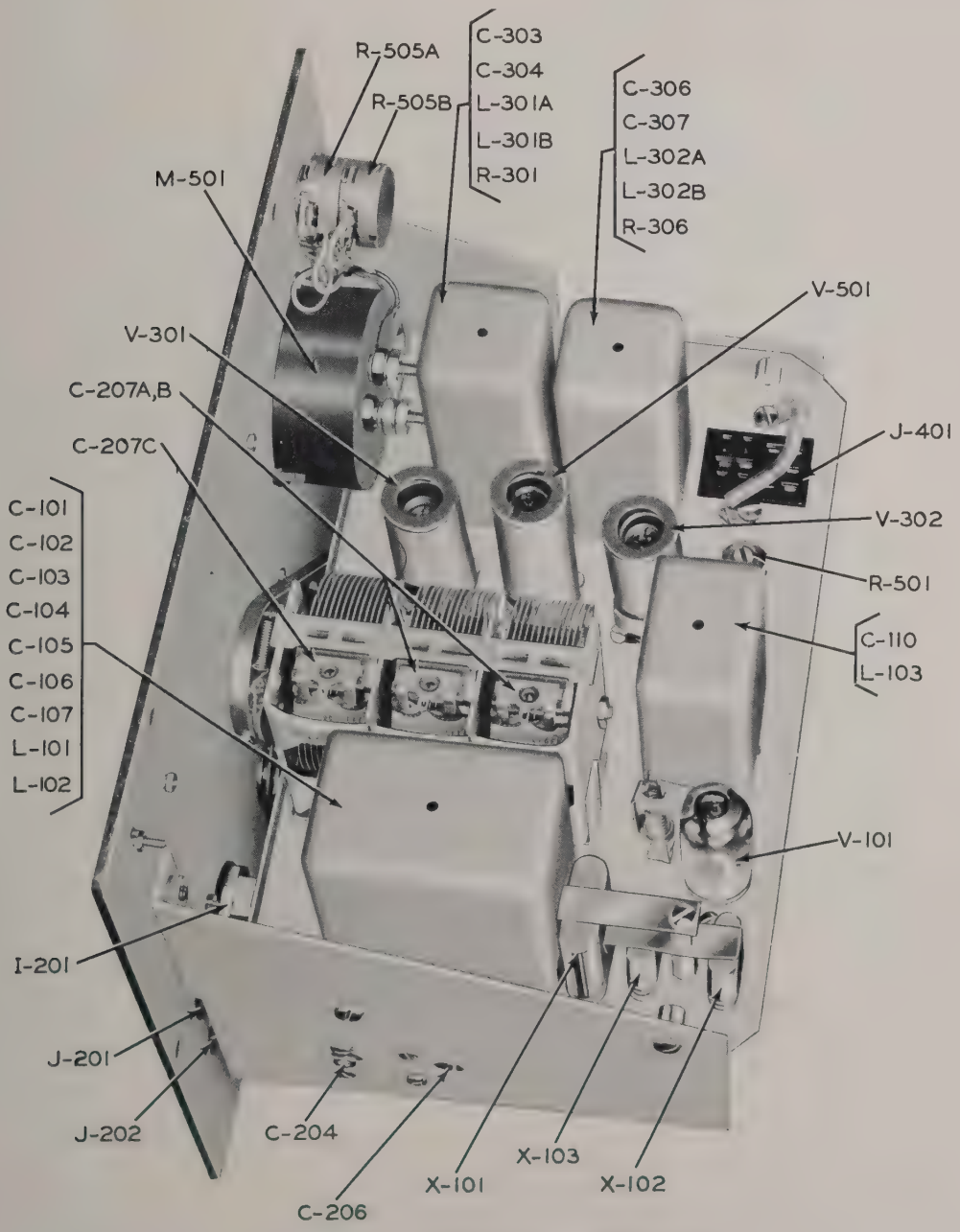


Figure 6. Top View — Main Chassis

low inductance side (adjusting screw of L-103 protruding further than at voltage maximum).

2. RED range: *Set Basis* on 0; vtvm on pin 1 of V-302 (6CS6), or switch lug 2-3.

Set 500 kc oscillator amplitude with L-101 to 85-90% of maximum voltage, on high inductance side (adjusting screw of L-101 protruding less than at voltage maximum).

3. WHITE range: Set Basis and vtvm as in Step 2.

Set 8 mc oscillator amplitude with L-102 to 85-90% of maximum voltage, on low inductance side (adjusting screw of L-102 protruding further than at voltage maximum).

4. WHITE range: *Set Basis* at 0; vtvm on pin 2 of V-501 (6BN6) or pin 5 of V-302 (6CS6). Adjust L-302 for maximum voltage.

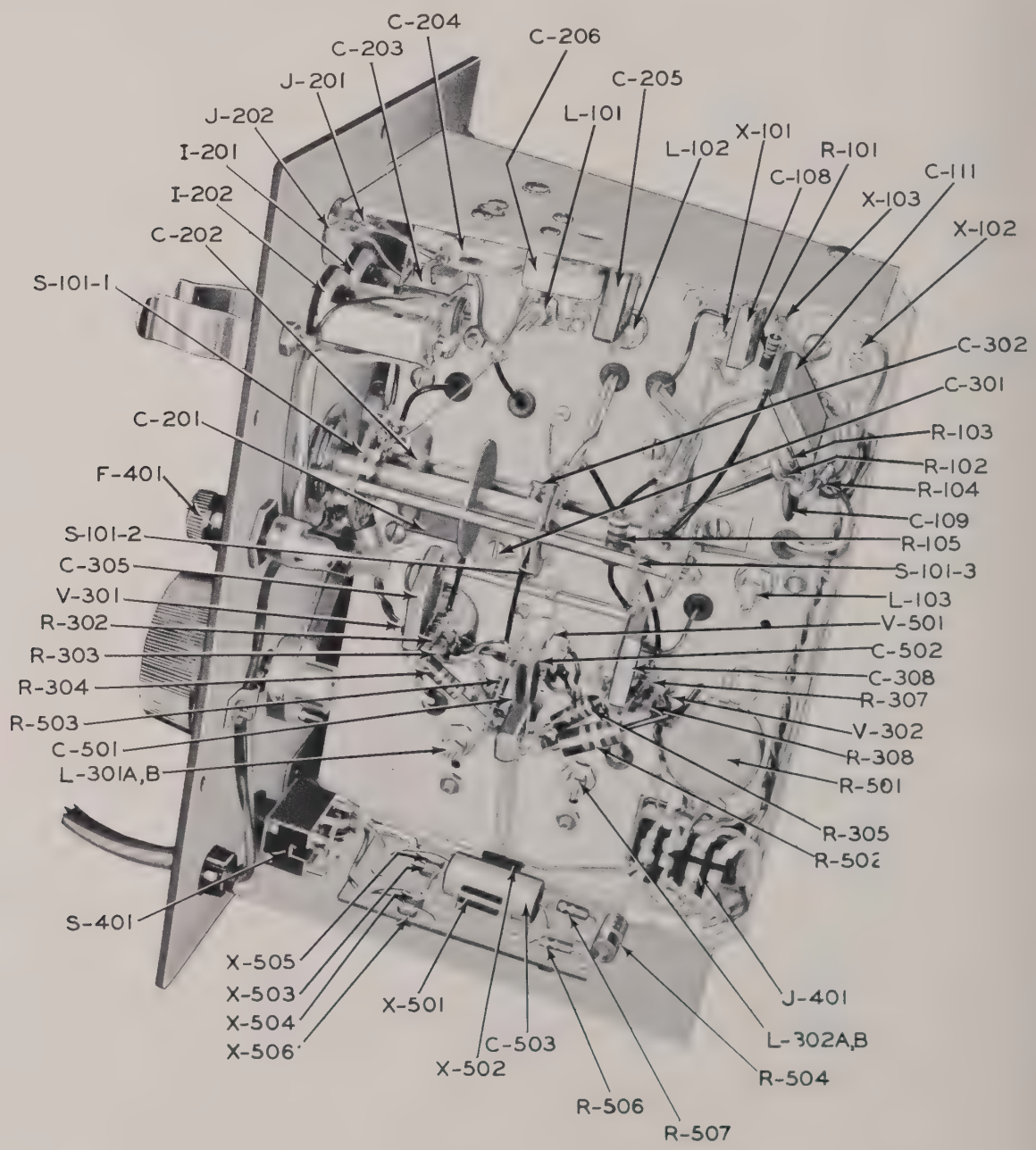


Figure 7.—Bottom View — Main Chassis

5. WHITE range: *Set Basis* at 0; vtvm on pin 6 of V-501 (6BN6), or pin 5 of V-301 (6CS6) or switch lug 2-11.

Adjust L-301 for maximum voltage.

6. WHITE range: *Set Standard* maximum clockwise; vtvm on pin 1 of V-301 (6CS6) or switch lug 1-11B, 12. Set WHITE gauge head on a flat piece of annealed copper.

a. Adjust *Set Basis* until vtvm reads maximum. Adjust C-204 if necessary.

b. Without removing gauge head from copper, adjust R-501 (25K Screwdriver Pot) to make "Thickness" meter M-501 read zero (maximum deflection upward towards *Basis* line).

7. RED range: RED gauge head placed on annealed copper; otherwise the same as Step 6.

a. Adjust *Set Basis* until vtvm reads maximum. Adjust C-206 if necessary.

b. Without removing gauge head from copper, adjust C-301 (4.5 — 25 $\mu\mu$f trimmer) until "Thickness" meter M-501 reads zero.

8. Remove vtvm: both gauge heads in free air, *Set Basis* at 30 on dial.

a. RED range; adjust C-206 until "Thickness" meter reads zero.

b. WHITE range; adjust C-204 until "Thickness" meter reads zero.

9. WHITE range: Place WHITE gauge head on annealed copper and note setting of *Set Basis* where "Thickness" meter reads zero.

Adjust gauge head spacer rod with adjustment screw in Gauge Head holder; if dial reading is over 105, turn screw clockwise; if less than 105, counterclockwise until zero occurs at 105 on *Set Basis* dial (see Figure10).

10. Repeat 6, 8b and 9 until "Thickness" meter reads zero under the following 3 conditions:

a. With vtvm on pin 1 of V-301, white gauge head on annealed copper and maximum reading on vtvm vs. adjustment of *Set Basis*.

b. With vtvm removed, WHITE gauge head on annealed copper and *Set Basis* close to 105.

c. With vtvm removed, WHITE gauge head in free air, *Set Basis* at 30.

If these conditions are satisfied, both the instrument and gauge head are aligned properly on the WHITE range.

11. RED range: The same as 9 except RED gauge head is to be used and desired *Set Basis* dial setting is 120.

12. Repeat 7, 8a and 11 until "Thickness" meter reads zero under 3 conditions.

a. vtvm on pin 1 of V-301, RED gauge head on annealed copper, maximum reading on vtvm vs. adjustment of *Set Basis*.

b. Without vtvm, RED gauge head on annealed copper, *Set Basis* close to 120 for thickness meter reading zero.

c. Without vtvm, RED gauge head in free air, *Set Basis* at 30. When 12a, b and c are satisfied, the instrument and gauge head are aligned properly on the RED range also.

EMERGENCY ALIGNMENT

If no instruments are available and the 255-A is apparently in otherwise good operating condition, but a tube needs replacement, this emergency alignment can be followed:

Set Basis on 30, gauge heads in free air.

1. WHITE range: adjust R-501 to make meter read zero.
2. RED range: adjust C-301 to make meter read zero.

RECALIBRATION ADJUSTMENTS FOLLOWING TUBE CHANGES

Tube Changed	Adjustment Steps
V-501 (6BN6)	6, 7, 8
V-301 (6CS6)	5, 6, 7, 8
V-302 (6CS6)	4, 6, 7, 8
Oscillator V-101 (12AU7)	1, 2, 3, 6, 7, 8
Gauge Head Spacers worn	8, 9, 11

INSTRUCTIONS FOR REMOVING POWER SUPPLY

(See Figure 9)

1. Remove main chassis to reach power supply chassis mounted in the rear of the cabinet.

2. Turn the cabinet so that cabinet opening faces up.

3. Remove two *Phillips* screws on power supply chassis located near top of right hand flange.

4. Remove *Phillips* screws located on *bottom* and *left* side of instrument.

5. Lift chassis out. It may be necessary to tip chassis to do this. Do not lift by electrolytic capacitor cans. Use finger grip provided on chassis.

STANDBY HEATER CIRCUIT

In hot, humid atmospheres corrosive vapors may seep into the case and condense out on the parts unless steps are taken to keep the instrument warm when the temperature drops at night. Therefore the power switch circuit has been arranged to leave about 15 watts of power continuously dissipated in the case when the power switch is in the *Off* position. This is done by leaving the voltage regulator permanently connected to the power line.

VOLTAGE CHART

NOTE: These measurements taken with —

DC 20,000Ω/v instrument.

AC with 1,000Ω/v instrument.

RF measurements with Hewlett-Packard 410-A vtvm. (input impedance: 6 megohms shunted with 1.3 $\mu\mu$f)

All measurements taken with Gauge Head in free air, *Set Basis* at Zero, unless otherwise indicated. Readings approximate only. Copper sample used must be at least 1 inch square, flat, and annealed.

Readings without range information do not depend on range or *Set Basis* setting.

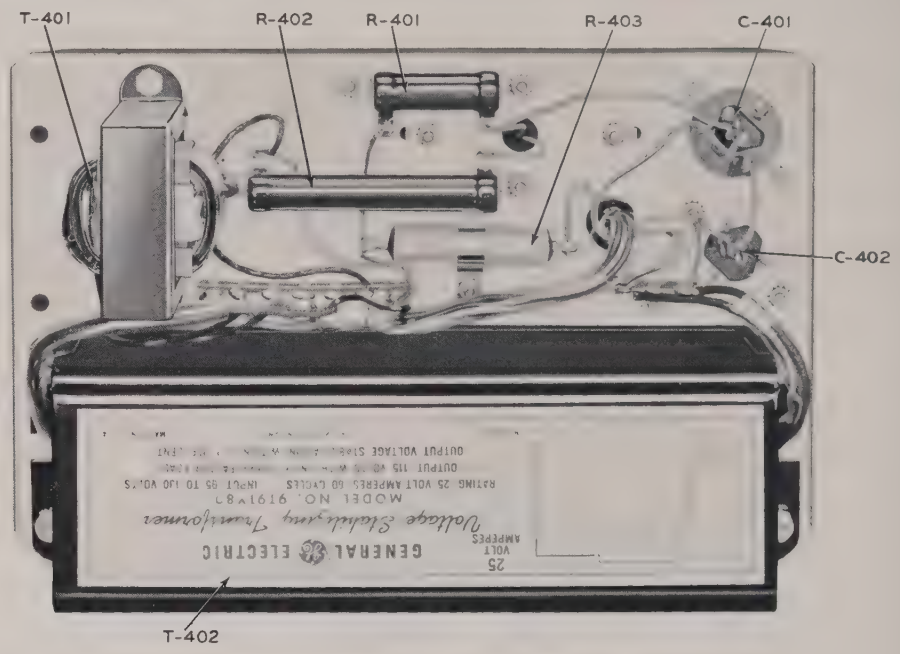


Figure 8. Power Supply — Rear View

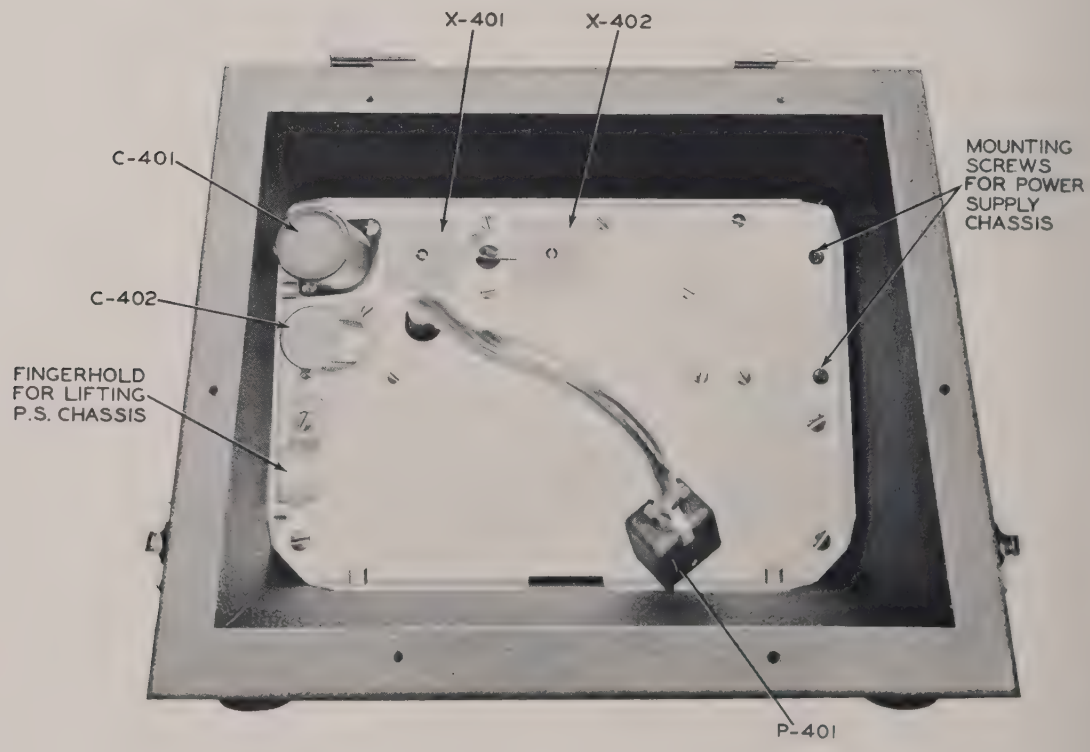


Figure 9. Power Supply — Front View

VOLTAGE CHART

V-101 (12AU7)

Pin No.	Range	DC	RF	Remarks
1		+120		
2		−16	45	33K Ω Resistor on tip of dc test lead
3		0	14	
4, 5			6.4 AC	
6	WHITE	+120	25	33K Ω Resistor on tip of dc test lead
6	RED	+120	45	33K Ω Resistor on tip of dc test lead
7	WHITE	−17	26	33K Ω Resistor on tip of dc test lead
7	RED	−18	15	33K Ω Resistor on tip of dc test lead
8	WHITE	+0.3	1.4	
8	RED	+0.1	0.3	
9		0	0	

V-301 (6CS6)

Pin No.	Range	DC	RF	Remarks
1	WHITE	−5	5	33K Ω Resistor on tip of dc test lead, on all dc measurements at Pin No. 1.
1	WHITE	−8	8.5	Gauge Head in free air, instrument balanced
1	WHITE	−6	6.5	Gauge Head on Copper, instrument balanced
1	RED	−1.8	1.4	
1	RED	−2	1.5	Gauge Head in free air, instrument balanced
1	RED	−1.5	0.9	Gauge Head on Copper, instrument balanced
2	WHITE	+0.3		
2	RED	+0.3		
3			6.4 AC	
4		0	0	
5	WHITE	+90	27	33K Ω Resistor on tip of dc test lead, on all dc measurements at pin No. 5.
5	WHITE	+90	24	Gauge Head in free air, instrument balanced
5	WHITE	+90	24	Gauge Head on Copper, instrument balanced
5	RED	+90	27	
5	RED	+90	27	Gauge Head in free air, instrument balanced
5	RED	+90	16	Gauge Head on Copper, instrument balanced
6		+90		
7		0	14	Same as Pin 3, V-101 and Pin 7, V-302

V-302 (6CS6)

Pin No.	Range	DC	RF	Remarks
1	WHITE	4.5	4	33K Ω Resistor on tip of dc test lead
1	RED	-1.8	1.2	33K Ω Resistor on tip of dc test lead
2	WHITE	+ 0.25		
2	RED	+ 0.3		
3			6.4 AC	
4		0	0	
5	WHITE	+ 90	16	33K Ω Resistor on tip of dc test lead
5	RED	+ 85	17	33K Ω Resistor on tip of dc test lead
6		+ 90		
7		0	14	Same as Pin 3, V-101 and Pin 7, V-301

V-501 (6BN6)

Pin No.	Range	DC	RF	Remarks
1		0	0	
2	WHITE		16	
2	RED		17	
3		0	0	
4			6.4 AC	
5		100		
6	WHITE		27	
6	WHITE		24	Gauge Head in free air, instrument balanced
6	WHITE		24	Gauge Head on Copper, instrument balanced
6	RED		27	
6	RED		27	Gauge Head in free air, instrument balanced
6	RED		16	Gauge Head on Copper, instrument balanced
7	WHITE	100	0.6	
7	WHITE	100	1.3	Gauge Head in free air, instrument balanced
7	WHITE	100	1.3	Gauge Head on Copper, instrument balanced
7	RED	100	0.9	
7	RED	100	1.3	Gauge Head in free air, instrument balanced
7	RED	100	1.3	Gauge Head on Copper, instrument balanced

J-401 (Jones Socket)

Pin No.	DC	AC	Remarks
1-4		95-135	
2-5		115	
3-6		115	
7	0	0	
8	0	0	
9	+155		
10		6.4	
11	+95		
12	+125		

SECTION VI
THEORY OF OPERATION

Most thickness measurement devices for obtaining absolute or comparative readings on the majority of film basis combinations are based on one of the following principles: mechanical, chemical, electrochemical, optical, X-ray and beta ray scattering, magnetic, electrical conductance, or eddy current properties. The Metal Film Gauge Type 255-A utilizes the last named principle, a brief description of which follows:

BASIC PRINCIPLE — EDDY CURRENT TESTING

When a conductor is brought into the field of a coil excited by an alternating current, eddy-currents are induced that circulate in closed loops in the conductor. The eddy-currents generate an electromagnetic field, which in turn induces an electromotive force in the exciting coil that tends to oppose the original current in it, thereby changing its impedance. The effect on the coil is equivalent to having introduced an additional "reflected impedance" in the coil.

The amount by which the coil impedance changes depends on a number of factors: the electrical and magnetic properties of the conductor, its configuration, the coil-conductor spacing, the geometry of the coil, and the frequency.

For the sake of simplicity, consider the case of a plane, infinite, homogeneous, non-ferromagnetic conductor close to the coil and normal to the coil axis. The following phenomena are observed:

As the coil is brought closer to the conducting plane, its reactance decreases while its effective series resistance increases. The relative reduction of the reactance depends mainly on the ratio of the coil diameter to the spacing from the conductor and is somewhat independent of the material of the conductor—provided this is non-ferromagnetic. The increase in resistance, however, depends not only on the coil spacing but also largely on the conductivity of the conductor. The combined effect of the change of reactance and resistance is to produce a change in phase in the Gauge Head circuit which is a measure of the conductivity of the conductor.

If the coil spacing and conductor material are kept constant but the thickness of the conducting sheet is varied, the reflected impedance of the coil follows the increase of the conductor thickness only up to a certain thickness, called the "penetration depth", beyond which eddy-currents do not appreciably penetrate into the metal. The penetration depth, T, in inches can be expressed as

$$T = \frac{3.5}{\sqrt{f}} \sqrt{\frac{\rho}{\mu . \rho_{Cu}}}$$

where:

f = frequency in cycles second

$\frac{\rho}{\rho_{Cu}}$ = ratio of resistivity of conductor to that of copper

μ = permeability of conductor

Figure 3, described previously, illustrates the dependence of eddy current penetration depths on frequency and conductivity for a variety of metals. Changes in thickness can be detected by observing the coil parameters only if the conductor is not thicker than T; after that its effect is as though it were infinitely thick. T is smaller for materials with high conductivity (low resistivity), ferromagnetic materials having very small penetration depths.

In the case of conductive coatings on conductors, the reflected impedance depends on the conductivities of the basis and coating and the thickness of the coating, with the coil spacing and frequency being kept constant. The relationships between reflected impedance and the properties of the composite conductor become quite complex, but it can be easily established that—

1. Changes in coating thickness are detectable only if the thickness of the coating is not more than the penetration depth in it, approximately, and an appreciable portion of the total eddy-currents circulates in the basis metal. If the coating thickness is larger than the penetration depth, practically all eddy-currents are confined to the coating metal and variations of its thickness have negligible effect on the distribution of the eddy-currents.

2. Combinations of the same basis material with coatings of different metals, but of the same thickness, result in different changes in reflected impedance referred to that on the bare basis. These changes are larger, if the coating and basis conductivities differ by a larger ratio, since a much larger fraction of the total eddy-currents is confined in the coating than in the case where both the coating and basis are very close in their conductivities.

The foregoing discussion is applicable to magnetic materials as well if we take into account that the "surface conductivity" is a function of permeability and frequency as well as bulk conductivity.

GAUGE HEAD COIL

The eddy-current induced by the coil in the conductor circulate in the latter and diminish in amplitude the greater the penetration into the material and distance from the coil along the surface. This decrease of the amplitude of the eddy-currents with distance from the coil determines the diameter of the coil which must not be greater than ½ the smallest linear dimension of the surface to be measured, or about ½" in diameter.

In general, variations of the resistance component of the reflected impedance are characteristic of the conductors in the coil field. Since this variation should be as large as possible in relation to the resistance of the coil itself for good sensitivity, the gauge head coil has been designed with a high Q. The sensitivity is further increased by operating the coil in a tuned circuit operating at or near resonance. Relative phase shifts in the current in the resonant circuit are a sensitive measure of the conductivity of the conductor in the field of the coil.

The spacing of the Gauge Head coil to the conductor (or their relative angular orientation, which is equivalent to a change of mean spacing) exerts a major influence on the reflected impedance. Means, therefore, are provided to guarantee that the spacing and orientation of the coil are always kept constant in use, and the coil has been designed flat so that it can come close to the specimen for greatest sensitivity.

Phase changes in the Gauge Head circuit are less affected by slight variations in coil spacing and orientation and reasonable surface imperfections (such as scratches, dirt, scale, etc.) than functions which also involve the magnitude of the impedance. Phase changes are also relatively independent of voltage levels. Therefore, the Metal Film Gauge is designed to detect changes in phase as an indication of film thickness.

A careful study of the coating-basis combinations and coating thicknesses commonly encountered in the plating art shows that 500 kc and 8 mc are suitable test frequencies. Together, they provide a continuous range of thickness measurements of about 20: 1 for any given combination of plating and basis material.

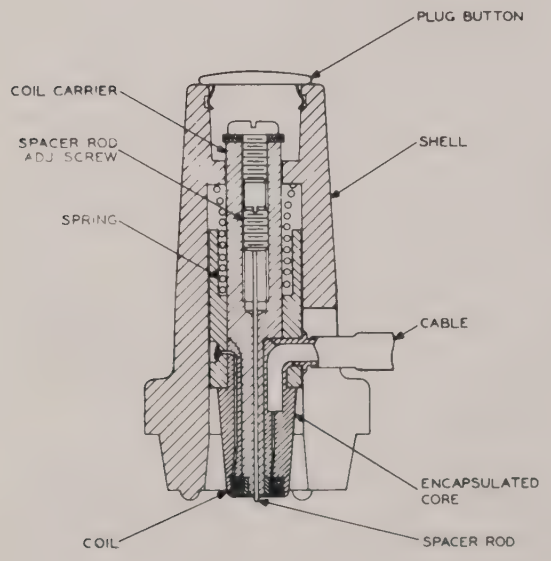


Figure 10. Gauge Head — Cross Section View

OVERALL OPERATION

Fundamentally the instrument consists of an oscillator driving the Gauge Head and a reference phase circuit. The Gauge Head circuit is made resonant at the oscillator frequency with the Gauge Head placed on the basis material. Both the Gauge Head signal and the reference signal are impressed, after suitable amplification and amplitude limiting, on the grids of a gated-beam phase detector tube. The indicating meter reads changes in the plate current of the phase detector tube which varies in accordance with the phase difference between the gauge head and the reference signals. The meter scales are easily interchangeable so that a direct reading on any plating-basis combination can be taken. This obviates the need for separate calibration curves.

BLOCK DIAGRAM

(See Figure 11)

Two complete gauge head assemblies go with the instrument, one for 500 kc (Red) and one for 8 mc (White). The test frequency, either 500 kc or 8 mc is generated in a crystal-controlled oscillator which can be switched to either of these frequencies by means of the *Gauge Head Selector Switch*. Since the limiting and phase detection circuits operate only at 500 kc, a 7.5 mc heterodyne oscillator frequency is provided for mixing with the 8 mc signals from the high frequency Gauge Head and reference phase circuits when in use.

The output of the oscillator is applied across the series combination of a coupling capacitor and the Gauge Head circuit which together form a phase shifting network.

A fraction of the total oscillator voltage, in phase with it, is obtained by tapping down across the capacitive voltage divider $C_1 - C_2$ and is used as the reference signal. With the Gauge Head coil resonated by the variable air capacitor labeled *Set Basis,* there exists a certain phase difference between the gauge head circuit and the reference signals which are fed to the grids of two identical limiter-amplifier-mixer heptodes, whose plate circuits are tuned to 500 kc. On the 500 kc range, the heptodes function as straight amplifiers. However, on the higher frequency (8 mc) range, the heptodes are made to act as mixers and to yield 500 kc signals in their outputs, transposing the phase difference from 8 mc to 500 kc.

The outputs of the heptode stages are impressed on the first and third grids of a gated-beam limiter-phase detector tube, type 6BN6. The amplitudes of these grid signals have been made sufficiently high so as to cause saturation, thus making the phase detector quite in-

sensitive to any changes in signal amplitudes. The average plate current is a linear function of the phase difference.

The plate circuit of the 6BN6 is part of a dc bridge containing facilities for bucking out the quiescent plate current (at Gauge Head resonance), an overload meter protection circuit, a sensitivity control labeled *Set Standard* which provides constant meter damping, and a full wave bridge rectifier. The meter readings are thus always unidirectional no matter how the basis and coating conductivities are related to each other. Full scale meter deflections at full sensitivity of the instrument correspond to phase angle changes of the order of 4°.

The sample cards carry a piece of the basis material and specimens of known plating thickness on this basis material together with the appropriately calibrated meter scale and are inserted in the holder in such a way that the calibration comes against the edge of the transparent meter case, thus making the instrument direct reading in thickness.

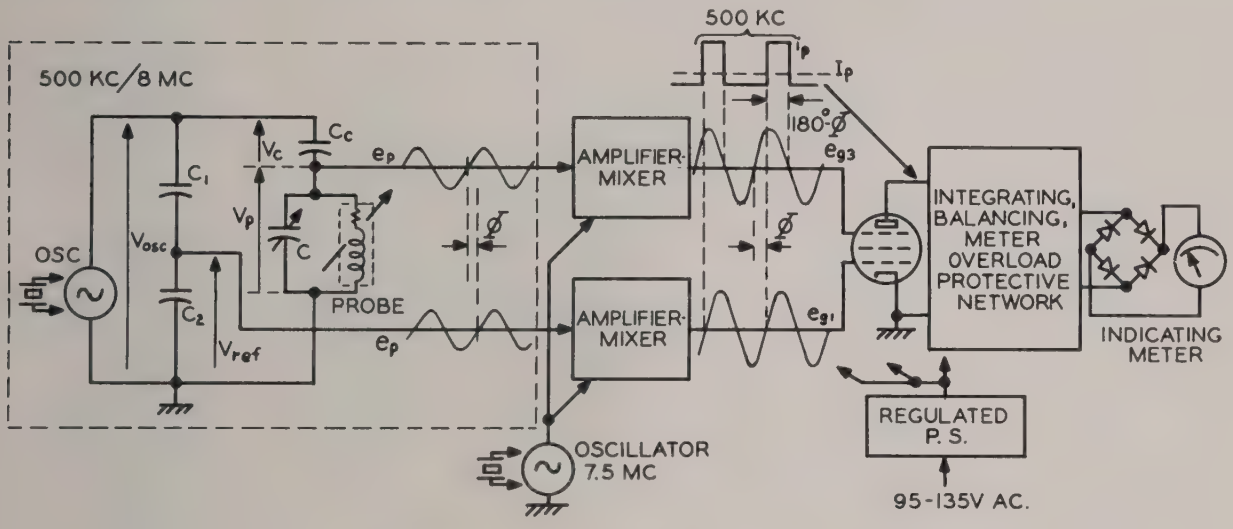


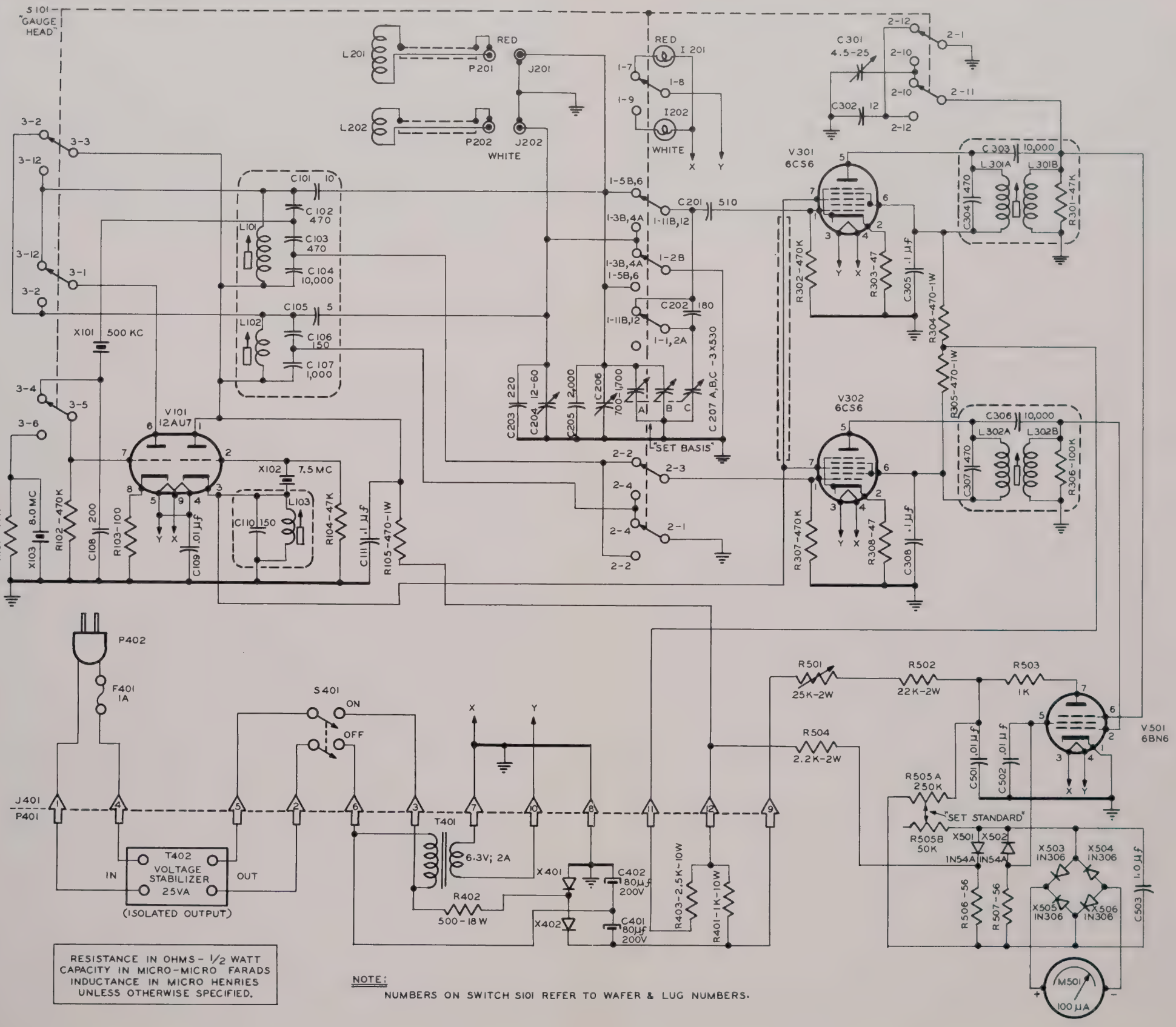
Figure 11. Functional Block Diagram

APPENDIX

ELECTRICAL COMPONENTS

Circuit Symbol	Value	Description	BRC Part No.
R-101	47KΩ	Resistor, Fixed ±5% 1/2W Carbon	80460
R-102	470KΩ	Resistor, Fixed ±5% 1/2W Carbon	80640
R-103	100Ω	Resistor, Fixed ±5% 1/2W Carbon	80062
R-104	47KΩ	Resistor, Fixed ±5% 1/2W Carbon	80460
R-105	470Ω	Resistor, Fixed ±5% 1W Carbon	80124
C-101	10μμf	Cap., Fixed ±2% 500V NPO	82011
C-102	470μμf	Cap., Fixed ±2% 500V Sil Mica	82239
C-103	470μμf	Cap., Fixed ±2% 500V Sil Mica	82239
C-104	10000μμf	Cap., Fixed ±2% 300V Sil Mica	82412
C-105	5μμf	Cap., Fixed ±0.25μμf ±30PPM 500V NPO	82003
C-106	150μμf	Cap., Fixed ±2% 500V Sil Mica	82203
C-107	1000μμf	Cap., Fixed ±2% 500V Mica	82312
C-108	200μμf	Cap., Fixed ±2% 500V Sil Mica	82208
C-109	0.01μf	Cap., Fixed HI.K Cer. Disc.	82428
C-110	150μμf	Cap., Fixed ±2% 500V Sil Mica	82203
C-111	.1μf	Cap., Fixed ±80%-20% 600V Cer.	83071
V-101		Tube, 12AU7	
L-101	500 kc	Coil Ass'y	A-303921
L-102	7.5 - 8 mc	Coil Ass'y	A-303536
L-103	7.5 - 8 mc	Coil Ass'y	A-303536
X-101	500 kc	Crystal	A-91087
X-102	7.5 mc	Crystal	A-91090
X-103	8.0 mc	Crystal	A-91088
S-101		Switch, Range	A-303905
C-201	510μμf	Cap., Fixed ±5% 500V Mica	82233
C-202	180μμf	Cap., Fixed ±2% 600V N220	82206
C-203	200μμf	Cap., Fixed ±2% 500V Sil Mica	82208
C-204	12-60μμf	Cap., Var. NPO Cer.	A-84060
C-205	2000μμf	Cap., Fixed ±2% Sil Mica	82316
C-206	700-1700μμf	Cap., Var. Cer.	A-84083
C-207-A, B, C	530μμf/sec	Cap., Var. (3 Sections)	A-84705
L-201	500 kc	Coil Ass'y.	A-303934
L-202	8 mc	Coil Ass'y.	A-303935
P-201		Plug, Screw On	303959
P-202		Plug, Screw On	303959
J-201		Receptacle	303960
J-202		Receptacle	303960
I-201		Pilot Light (Red)	A-303876
I-202		Pilot Light (White)	A-303885
R-301	47KΩ	Resistor, Fixed ±5% 1/2W Carbon	80460
R-302	470KΩ	Resistor, Fixed ±5% 1/2W Carbon	80640
R-303	47Ω	Resistor, Fixed ±5% 1/2W Carbon	80041
R-304	470Ω	Resistor, Fixed ±5% 1W Carbon	80124
R-305	470Ω	Resistor, Fixed ±5% 1W Carbon	80124
R-306	100KΩ	Resistor, Fixed ±5% 1/2W Carbon	80517
R-307	470KΩ	Resistor, Fixed ±5% 1/2W Carbon	80640
R-308	47Ω	Resistor, Fixed ±5% 1/2W Carbon	80041

Circuit Symbol	Value	Description	BRC Part No.
C-301	4.5-25$\mu\mu$f	Cap., Var. NPO Cer.	A-84005
C-302	12$\mu\mu$f	Cap., Fixed $\pm$2% 500V NPO Cer.	82113
C-303	10000$\mu\mu$f	Cap., Fixed $\pm$5% 300V Mica	82416
C-304	470$\mu\mu$f	Cap., Fixed $\pm$2% 500V Sil Mica	82239
C-305	.1μf	Cap., Fixed +80%-20% 600V Cer.	83071
C-306	10000$\mu\mu$f	Cap., Fixed $\pm$5% 300V Mica	82416
C-307	470$\mu\mu$f	Cap., Fixed $\pm$2% 500V Sil Mica	82239
C-308	.1μf	Cap., Fixed +80%-20% 600V Cer.	83071
V-301		Tube, 6CS6	
V-302		Tube, 6CS6	
L-301 A, B	500 kc	Coil Ass'y	A-303541
L-302 A, B	500 kc	Coil Ass'y	A-303541
R-401	1K 10W	Resistor, Fixed	A-80192
R-402	500Ω 18W	Resistor, Fixed	A-80231
R-403	2.5K 10W	Resistor, Fixed	A-80226
C-401	40-40μf	Cap., Fixed 200V Elec. Ins.	83093
C-402	40-40μf	Cap., Fixed 200V Elec. Ins.	83094
X-401	100 MA DC	Rectifier Selenium	A-300316
X-402	100 MA DC	Rectifier Selenium	A-300316
T-401		Transformer Fil.	A-303568
T-402	25 VA 60~	Voltage Stabilizer	A-303709
	25 VA 50~ (For 255AP only)	Voltage Stabilizer	A-303708
P-401		Plug Jones 12 Prong	303565
P-402		Power Cord	A-01019
J-401		Socket Jones 12 Prong	303566
S-401		Switch, Power	A-88059
F-401		Fuse, 1 Amp.	301068
R-501	25KΩ	Resistor, Var. $\pm$10% 2W	A-81415
R-502	22KΩ	Resistor, Fixed $\pm$5% 2W Carbon	80481
R-503	1KΩ	Resistor, Fixed 1/2W	80148
R-504	2.2KΩ	Resistor, Fixed $\pm$10% 2W	80277
R-505A, B	50KΩ, 250KΩ	Resistor, Var. $\pm$20%	A-81421
R-506	56Ω	Resistor, Fixed $\pm$5% 1/2W Carbon	80710
R-507	56Ω	Resistor, Fixed $\pm$5% 1/2W Carbon	80710
C-501	0.01μf	Cap., Fixed HiK Cer. Disc	82428
C-502	0.01μf	Cap., Fixed HiK Cer. Disc	82428
C-503	1.0μf	Cap., Fixed 200WV Met Paper	83101
V-501		Tube, 6BN6	
X-501		Crystal, Diode 1N54A	91091
X-502		Crystal, Diode 1N54A	91091
X-503		Crystal, Diode 1N306	91089
X-504		Crystal, Diode 1N306	91089
X-505		Crystal, Diode 1N306	91089
X-506		Crystal, Diode 1N306	91089
M-501		Meter	B-303558



RESISTANCE IN OHMS - 1/2 WATT
CAPACITY IN MICRO-MICRO FARADS
INDUCTANCE IN MICRO HENRIES
UNLESS OTHERWISE SPECIFIED.

NOTE:
NUMBERS ON SWITCH S101 REFER TO WAFER & LUG NUMBERS.

255-A Schematic Diagram

MP MASTER
MA24352